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A

LAW OFFICES
BARRY R. LIPSITZ
BRADFORD GREEN, BUILDING 8
755 MAIN STREET
MONROE, CONNECTICUT 06468

PATENTS, TRADEMARKS, COPYRIGHTS

BARRY R. LIPSITZ
KEITH F. HOPPIN
DOUGLAS M. McALLISTER

TELEPHONE: (203)459-0200
FACSIMILE: (203)459-0201

jc872 U.S. PTO 09/665372 09/20/00
jc760 U.S. PTO 09/665372 09/20/00

BOX PATENT APPLICATION
Commissioner for Patents
Washington, D.C. 20231

UTILITY PATENT APPLICATION TRANSMITTAL
FILED UNDER 37 C.F.R. §1.53(b)

Sir:

Transmitted herewith for filing is the patent application of:

Inventor(s): **Vincent LIU, Robert S. NEMIROFF, Siu-Wai WU, Ajay LUTHRA and Limin WANG**

Title: **PROCESSING MODE SELECTION FOR CHANNELS IN A VIDEO MULTI-PROCESSOR SYSTEM**

APPLICATION ELEMENTS:

(1) [X] Patent Application Specification, including Abstract and claims - 34 pages
(2) [X] Seven (7) sheets of formal drawings, together with transmittal letter
(3) [X] A check in the amount of $856 to cover the [X] filing fee ($816.00) and/or [X] Assignment Recordal Fee ($40) is enclosed.

[ ] Before calculating the fee, cancel claim(s)
[ ] Before calculating the fee, see copy of Preliminary Amendment filed in parent application _____ (attached hereto.)

Basic Fee								$ 690.00
Multiple Dependent Claims ($260.)								
Foreign Language Surcharge ($130.)								
	For	No. Filed	-	No. Extra		Rate		
EXTRA	Total Claims	27	20	7	x	$18.	=	$ 126.00
CLAIMS	Independent Claims	2	3	0	x	$78.	=	$ 0.00
						TOTAL FILING FEE	=	$ 816.00

[X] The Commissioner is hereby authorized to charge any deficiency in the payment of the required fee(s) or credit any overpayment to Deposit Account No. 50-0625.

(4) [X] Declaration and Power of Attorney form -- 3 pages
- a. [X] Newly executed
- b. [ ] Copy from a prior application
- c. [ ] Deletion of inventor(s) – signed statement attached deleting inventor(s) named in the prior application.

(5) [ ] Small Entity Declaration
- a. [ ] Newly executed
- b. [ ] Copy from a prior application. Status still proper and desired.

ACCOMPANYING APPLICATION PARTS:

(6) [X] Assignment document
- a. [X] Newly executed (with $40.00 recordal fee) and separate transmittal Form PTO-1595
- b. [ ] Copy from a prior application

(7) [ ] Preliminary Amendment

(8) [ ] Certified Copy of Priority Document, together with separate transmittal letter

(9) [ ] Information Disclosure Statement, together with PTO Form 1449 and copies of cited references

(10) [X] Return receipt postage prepaid postcard

(11) [X] Express Mail Certificate (Mailing Label No. EL 632260034 US)

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Examiner: _____ Group/Art Unit:_____
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FOR CONTINUATION or DIVISIONAL APPLICATIONS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under paragraph 4(b) above, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

(14) [ ] Please amend the specification by inserting before the first line the sentence:

(15) [ ] This application claims the benefit of _____ Patent Application No. _____ filed on _____.

(16) [X] Correspondence address:
Barry R. Lipsitz
Law Offices of Barry R. Lipsitz
755 Main Street, Building 8
Monroe, CT 06468
Telephone: (203) 459-0200

Respectfully submitted,

Barry R. Lipsitz
Attorney for Applicant(s)
Registration No. 28,637
755 Main Street
Monroe, CT 06468
(203) 459-0200

ATTORNEY DOCKET NO.: GIC-619
Date: September 20, 2000

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:)
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Liu et al.)
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Application No.:)
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Filed: Herewith)
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For: **PROCESSING MODE SELECTION FOR CHANNELS IN A VIDEO MULTI-PROCESSOR SYSTEM**

BOX PATENT APPLICATION
Commissioner for Patents
Washington, D.C. 20231

EXPRESS MAIL CERTIFICATE

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are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 C.F.R. 1.10 on the date indicated above and is addressed to: **BOX PATENT APPLICATION, Commissioner for Patents, Washington, D.C. 20231**

Michele Hollis
(Typed or printed name of person mailing paper or fee)

Michele Hollis
(Signature of person mailing paper or fee)

Respectfully submitted,

Date: **September 20, 2000**
ATTORNEY DOCKET NO.: **GIC-619**

Barry R. Lipsitz
Attorney for Applicant(s)
Registration No. 28,637
755 Main Street
Monroe, CT 06468
(203) 459-0200

PROCESSING MODE SELECTION FOR CHANNELS IN A VIDEO MULTI-PROCESSOR SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to a system having one or more processors, such as for the transcoding of digital video signals.

Commonly, it is necessary to adjust a bit rate of digital video programs that are provided, e.g., to subscriber terminals in a cable television network or the like. For example, a first group of signals may be received at a headend via a satellite transmission. The headend operator may desire to forward selected programs to the subscribers while adding programs (e.g., commercials or other content) from a local source, such as storage media or a local live feed. Additionally, it is often necessary to provide the programs within an overall available channel bandwidth.

Accordingly, the statistical remultiplexer (stat remux), or transcoder, which handles pre-compressed video bit streams by re-compressing them at a specified bit rate, has been developed. Similarly, the stat mux handles uncompressed video data by compressing it at a desired bit rate.

In such systems, a number of channels of data are processed by a number of processors arranged in parallel. Each processor typically can accommodate multiple channels of data. Although, in some cases,

such as for HDTV, which require many computations, portions of data from a single channel are allocated among multiple processors.

However, there is a need for a single or multi-processor system that selects a processing mode for each video frame to minimize transcoding artifacts, which can appear as visible noise in the transcoded image data. The system should also ensure that the total processing cycles that are required to process frames in buffers of the individual processor or processors do not exceed the available processing power of the transcoders.

The present invention provides a processor system having the above and other advantages.

SUMMARY OF THE INVENTION

The present invention relates to a system having one or more processors, such as for the transcoding of digital video signals.

Within each channel, a processing mode is dynamically selected for each picture to maximize the video quality subject to the processing cycle budget constraint/throughput.

For example, for transcoding, if there is an unlimited throughput, "full transcoding" can be performed on every frame. However, because the throughput is constrained, some of the frames may be processed in a "requantization" mode or even a "pass through" (bypass) mode, which can result in additional artifacts. In accordance with the invention, an algorithm is used to select a processing mode for each frame such that the video quality is optimized subject to the limited throughput of the processor.

Generally, a range of processing modes that have different computational intensities are provided so that a less intensive mode can be selected when required to avoid a backup of unprocessed frames.

A particular method in accordance with the invention is suitable for a single processor or a multi-processor system. Specifically, a method for processing compressed video data comprising video frames includes the steps of: maintaining a budget of a number of processing cycles that are available at a

processor to process the data, maintaining an estimate of the number of processing cycles required by the processor to process the data, and providing the compressed video data to the processor.

The processor operates in a plurality of modes, such as a full transcoding mode, an abbreviated, requantization mode, and a bypass mode. A mode is selected for processing each video frame according to a relationship between the number of budgeted processing cycles and the estimated number of required processing cycles. That is, a less computationally intensive mode is selected when the required processing cycles begin to exceed the budgeted, or available, processing cycles.

A corresponding apparatus is also presented.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a multi-processor system in accordance with the invention.

FIG. 2 illustrates a method for assigning channels of compressed data to a transcoder in a multi-transcoder system in accordance with the invention.

FIG. 3(a) illustrates a prior art transcoder that performs full transcoding, which is one of the transcoding modes that may be selected in accordance with the invention.

FIG. 3(b) illustrates a simplified transcoder that performs full transcoding, which is one of the transcoding modes that may be selected in accordance with the invention.

FIG. 4 illustrates a transcoder that performs re-quantization of frames in the DCT domain, without motion compensation, which is one of the transcoding modes that may be selected in accordance with the invention.

FIG. 5 illustrates a smoothing buffer for absorbing the variable processing time for different transcoding modes in accordance with the invention.

FIG. 6 illustrates the processing of a frame at a transcoder processing element (TPE) in accordance with the invention.

FIG. 7 illustrates the selection of a processing mode for a frame at a TPE in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a system having one or more processors, such as for the transcoding of digital video signals.

FIG. 1 illustrates a multi-processor system, shown generally at 100, in accordance with the invention.

L channels of compressed data are provided to a switch 130 that is analogous to a demultiplexer. The channels may be provided via a transport multiplex, e.g., at a cable television headend. Some of the channels may be received via a remote distribution point, such as via a satellite, while other channels may be locally provided, such as locally-inserted commercials or other local programming. Conventional demodulation, grooming, buffering steps and the like are not shown, but should be apparent to those skilled in the art.

The switch 130, under the control of a controller 155, routes the channels to one of M transcoders, e.g., transcoder 1 (160), transcoder 2 (170), …, transcoder M.

The transcoded data is output via a bus 190, multiplexed at a mux 195, and transmitted via a transmitter 197, e.g., to a terminal population in a cable television network.

A sample (e.g., segment) of each channel is also provided to an analyzer 140, which uses an associated memory 145 to store the samples and analyze them. The

results of this analysis are used by the controller 155 in assigning the channels to the different transcoders 160, 170, …, 180. The individual transcoders 160, 170, …, 180 are also referred to herein as "Transcoder core Processing Elements" or TPEs.

The TPEs are allocated to process the incoming video frames in the different channels when a reconfiguration is required, e.g., when the input channels change (e.g., due to adding, removing or replacing). Note that L can be less than, equal to, or greater than M. That is, a TPE may process more than one channel, e.g., for standard definition television (SDTV), or a single channel may be processed by more than one TPE, e.g., for high-definition television (HDTV), which is much more computationally intensive.

At the TPEs, the channels are parsed to decode the picture types therein, e.g., I, P or B pictures, as known from the MPEG standard, for use in selecting an appropriate transcoding mode for each frame to minimize the transcoding artifacts.

The invention minimizes the transcoding artifacts subject to the constraint that the average throughput required to transcode each frame at the TPE does not exceed the available processing power of the TPE.

Note that while multiple processors are shown in FIG. 1, the embodiment of the invention for the selection of cycle-saving modes on the transcoder core processing elements is also suitable for use with a

single transcoder which receives one or multiple input channels.

I. Allocation of channels among the transcoder core processing elements (TPEs).

FIG. 2 illustrates a method for assigning channels of compressed data to TPEs in a multi-transcoder system in accordance with the invention.

The goal of the allocation technique is to share workload equally among the TPEs to maximally utilize these resources.

At box 200, the transcoders are initialized so that an associated accumulated complexity value and an accumulated resolution value are reset to zero.

At box 210, the bitstream analyzer 140 captures in its associated memory 145 a sample of input bitstream from each video channel (box 210). The bitstream analyzer 140 estimates the processing cycle requirement (e.g., complexity (Comp[i]) discussed below) for each channel based on the picture types (I, B or P) and a resolution of the frames in the captured samples, which is defined as the average number of macroblocks per second in the input bitstream (i.e., an average macroblock rate).

A complexity measure is determined for each i-th channel as a function of the number of B frames and the resolution (box 220). Specifically, the following complexity measure format may be used.

*Comp [i] = F (M [i]) * Res[i] * U[i] * G_{CBR} (Input bit rate[i] - Output bit rate[i]),*

where M[i] (M=1,2,3, or higher) is one plus the ratio between the number ("#")of B frames and the number of P and I frames in the segment (i.e., 1 + #B / (#P + #I); Res[i], the channel resolution, is the average number of macroblocks per second (i.e., an average macroblock rate); and U[i] is a user-controlled parameter that sets a priority of the channel, if desired. For a higher priority, average priority, or lower priority channel, set U[i]>1, U[i]=1, or U[i]<1. respectively.

If both the input and output of the channel are constant bit rate (CBR), one more factor, G_{CBR}( ), which is determined by the difference between input and output bit rate, may be applied. The analyzer 140 can determine the input bit rate, e.g., using a bit counter, and the output bit rate is set by the user.

Experimental or analysis data can be used to determine the functions F( ) and G_{CBR} ( ). For example: F(M) = (alpha * (M-1) + 1) / M, where alpha (e.g., 0.75) is ratio of the nominal complexity of a B frame to the nominal complexity of a P frame. Also, as an example: G_{CBR} (R) = beta * R, where beta = 0.25 per Mbps.

At box 230, once the complexity estimates are calculated, an iterative "greedy" algorithm can be used to assign the channels to the TPEs as follows. During the assignment process, keep track of an accumulated

complexity value for each TPE, which is a sum of the complexity measure of each channel that is assigned to a TPE. The accumulated complexity is an indication of the processing cycles that will be consumed by each TPE when the channels are assigned to it. Optionally, keep track of an accumulated resolution, which is a sum of the resolution of each channel that is assigned to a TPE.

For assigning the channels to the TPEs, arrange an array of complexity values, Comp[], in descending order. For the assignment of an initial channel, assign the unassigned channel of highest complexity to a first TPE, such as TPE 160. The first-assigned TPE can be chosen randomly, or in a arbitrarily predefined manner, since all TPEs have an equal accumulated complexity of zero at this time.

Generally, if there is a tie in the channels' complexity values, select the channel with the highest resolution. If there is a tie again, select the lower channel number or, otherwise, select randomly from among the tied channels.

For the assignment of channels after the initial channel, select the TPE that has the lowest value of accumulated complexity. If there is a tie, choose the TPE with lower accumulated resolution. If there is a tie again, choose the TPE with the smaller number of channels already assigned to it. If there is a tie again, choose the TPE with a lower TPE number, or otherwise randomly from among the tied TPEs.

At box 240, a check is made to determine if the assignment of the channel will result in an overload of the TPE. This may occur when a sum of the accumulated resolution and the resolution of the selected channel exceeds some predefined upper bound that is specific to the processing power of the TPE.

At box 250, if it is determined that the assignment of the channel with the highest complexity among the unassigned channels would result in an overload condition, the channel is assigned to the transcoder with the next lowest accumulated complexity.

If no such overload condition is presented, increment the accumulated complexity of the TPE that just had a channel assigned to it by the complexity of the assigned channel (box 260). Also, increment the accumulated resolution of the TPE by the resolution of the assigned channel.

At box 270, if all channels have been assigned to a transcoder, the process is complete, and wait until the next reconfiguration (box 280), when the process is repeated starting at box 200. If additional channels are still to be assigned, processing continues again at box 230 by assigning the remaining unassigned channel with the highest complexity to a TPE with the lowest accumulated complexity without overloading a TPE.

II. Selection of cycle-saving modes on the transcoder core processing elements.

Overview

In accordance with the invention, each TPE 160, 170, …, 180 selects an efficient mode for transcoding the frames of data from the channels assigned thereto. The following set of tools (transcoding modes) has been identified as providing viable transcoding strategies. Each tool is associated with a complexity requirement and an amount of artifacts. A different transcoding mode may be selected for every frame.

The transcoding modes include: (1) a full transcoding mode, (2) a requantization mode, and (3) a passthrough/bypass mode

(1). Full transcoding is most computationally intensive but results in the least amount of artifacts. Full transcoding can comprise full decoding and re-encoding, with adjustment of the quantization level, Q_2, during re-encoding.

A simplified full transcoder, discussed in FIG. 3(b), may also be used.

Generally, the term "full transcoding" as used herein refers to transcoding where motion compensation is performed. Other processing, such as inverse quantization, IDCT, DCT and re-quantization are also typically performed.

FIG. 3(a) illustrates a prior art transcoder that performs full or regular transcoding, which is one of the transcoding modes that may be selected in accordance with the invention.

A straightforward transcoder can simply be a cascaded MPEG decoder and encoder. The cascaded

transcoder first decodes a compressed channel to obtain a reconstructed video sequence. The reconstructed video sequence is then re-encoded to obtain a different compressed bitstream that is suitable for transmission, e.g., to a decoder population.

In particular, the transcoder 300 includes a decoder 310 and an encoder 350. A pre-compressed video bitstream is input to a Variable Length Decoder (VLD) 315. A dequantizer function 320 processes the output of the VLD 315 using a first quantization step size, Q_1. An Inverse Discrete Cosine Transform (IDCT) function 325 processes the output of the inverse quantizer 320 to provide pixel domain data to an adder 330. This data is summed with either a motion compensation difference signal from a Motion Compensator (MC) 335 or a null signal, according to the position of a switch 340.

The coding mode for each input macroblock (MB), either intra or inter mode, embedded in the input pre-compressed bit stream, is provided to the switch 340. The output of the adder 330 is provided to the encoder 350 and to a Current Frame Buffer (C_FB) 345 of the decoder 310. The MC function 335 uses data from the current FB 345 and from a Previous Frame Buffer (P_FB) 351 along with motion vector (MV) data from the VLD 315.

In the encoder 350, pixel data is provided to an intra/inter mode switch 355, an adder 360, and a Motion Estimation (ME) function 365. The switch 355 selects

either the current pixel data, or the difference between the current pixel data and pixel data from a previous frame, for processing by a Discrete Cosine Transform (DCT) function 370, quantizer 375, and Variable Length Coding (VLC) function 380. The output of the VLC function 380 is a bitstream that is transmitted to a decoder. The bitstream includes Motion Vector (MV) data from the ME function 365.

The bit output rate of the transcoder is adjusted by changing Q_2.

In a feedback path, processing at an inverse quantizer 382 and an inverse DCT function 384 is performed to recover the pixel domain data. This data is summed with motion compensated data or a null signal at an adder 386, and the sum thereof is provided to a Current Frame Buffer (C_FB) 390. Data from the C_FB 390 and a P_FB 392 are provided to the ME function 365 and a MC function 394. A switch 396 directs either a null signal or the output of the MC function 394 to the adder 386 in response to an intra/inter mode switch control signal.

FIG. 3(b) illustrates a simplified transcoder that performs full (regular) transcoding, which is one of the transcoding modes that may be selected in accordance with the invention. Like-numbered elements correspond to those of FIG. 3(a).

The transcoder architecture 300' performs most operations in the DCT domain, so both the number of inverse-DCT and motion compensation operations are

reduced. Moreover, since the motion vectors are not recalculated, the required computations are dramatically reduced. This simplified architecture offers a good combination of both low computation complexity and high flexibility.

(2). The second transcoding mode is to apply only re-quantization to a frame, without motion compensation, as shown in FIG. 4. Generally, IDCT and DCT operations are avoided. This strategy incurs lower complexity than the first approach. If the picture is a B-frame, there is a medium amount of artifacts. If the picture is an I- or P-frame, there is a larger amount of artifacts due to drifting. Here, the DCT coefficients are de-quantized, then re-quantized.

FIG. 4 illustrates a transcoder 400 that performs re-quantization of frames in the DCT domain, without motion compensation, which is one of the transcoding modes that may be selected in accordance with the invention.

A VLD 410 function and an inverse quantization function 420 are used. Re-quantization occurs at a different quantization level at a function 430, and VLC is subsequently performed at a function 440.

(3). A third transcoding mode, or processing mode, is to passthrough (bypass) the bit stream without decoding or re-encoding. This strategy involves delaying the bitstream by a fixed amount of time, and has a complexity cost of almost zero, but is applicable only for small differences between the input and output

bit rate. A statmux algorithm can be used to determine the output bit rate, hence determine if this mode should be used.

Effects of Delaying Encode Time

FIG. 5 illustrates a smoothing buffer for absorbing the variable processing times at the processors for the different transcoding modes in accordance with the invention. A video buffer verifier (vbv) buffer 510, partial decode function 520, smoothing buffer 530 (with a capacity of, e.g., five frames), and a transcode function 560 are provided. The function 520 includes a VLD, and also parses the bitstream header information, e.g., picture header to determine whether a picture is I, P or B frame. A vbv buffer simulates the buffer at a decoder. Note that the smoothing buffer 530 is after the vbv buffer 510, not before it. The smoothing buffer 530 and vbv buffer 510 are separate buffers, although they may share the same memory in an implementation.

Full transcoding may take more than a frame time to execute, while the requantizing and passthrough transcoding modes may take less than a frame time to execute, in which case, the smoothing buffers 162, 172, …, 182 that each store up to, e.g., five input frames can be used to absorb the delay. This buffer should be on the TPEs. Moreover, there should be one such buffer for each video channel. At each TPE, a single buffer element can be apportioned among the different channels, or separate buffer elements can be used.

Processing mode selection

In this section, assume that a selection has been made to process one video frame from one of, e.g., three channels assigned to a TPE. Generally, when more than one channel is assigned to a TPE, one frame is processed from each channel in turn in a rotating fashion. The selection of the transcoding mode for that frame of video is now discussed.

Before a frame in a channel is selected for processing at a TPE, examine the processing cycles budgeted for the channel, and determine how far the video channel is deviating from its assigned budget. The deviation is measured in terms of a running sum for each channel defined as: deficit = old_deficit + actual_cycles_used - frame_budget, where frame budget is defined as the cycle-budget per frame for that channel, and is computed as:

frame_budget = (total cycles per second available on the TPE * complexity of the channel / sum of complexity of all channels processed by the TPE) / frame rate of the channel,

where the complexity measure of the channels are calculated during the channel allocation algorithm.

If the deficit on any channel exceeds a predetermined multiple of the frame_budget, a "panic mode" is invoked. For example, when the TPE buffer has a capacity of five frames, the panic mode may be invoked when the deficit exceeds four frames. Generally, the panic mode may be invoked when the

deficit approaches the TPE buffer capacity (of the smoothing buffer 530). It is also possible to measure the actual fullness of the smoothing buffer to determine if the panic mode should be invoked. The panic mode indicates that the buffered frames need to be transcoded and output as soon as possible to avoid a buffer overflow.

The panic mode causes the frame that is processed next to be processed choosing the requantize mode, and only the lower order coefficients are requantized. That is, the higher frequency DCT coefficients are dropped. The range of lower frequency coefficients that are processed may vary depending on the current deficit.

In particular, the number of lower coefficients that are coded is adjusted based on the magnitude of the current deficit with respect to frame_budget. For example, if the deficit exceeds 4.6*frame_budget, then only the lower six coefficients are coded. Since the smoothing buffer stores only five input frames in the present example, it is necessary to "apply the brakes" when the deficit approaches five frames. While the value 4.6 has been used successfully, other values may be used, and the value used should be adjusted based on the number of frames that can be stored in the input buffer. The value may also be expressed in terms of a fractional buffer fullness, e.g., 4.6/5=0.92 or 92%.

Here, the coefficients are arranged in either of two zig-zag scanning orders, one for interlaced and the

other for progressive picture. The number six is selected so that in either scan order, the lowest frequency 2x2 block of coefficients is preserved. This can be understood further by referring to the two ways in which DCT coefficients can be scanned, as explained in section 7.3 "Inverse scan" of the MPEG-2 specification, ISO/IEC 13818-2.

One may select different limits for P-frames vs. B-frames in choosing the range of coefficients that are coded (or, conversely, dropped) as a function of the current TPE deficit. For the present example, the same limit is used. The following table is an example implementation that shows the relationship between the deficit and the range of coefficients that are quantized. This refers to the number coefficients coded in each 8x8 DCT block of a MB (each MB has four luma and two chroma 8x8 blocks).

If deficit >	Range of lower coefficients coded:
4.0 * frame_budget	24
4.2 * frame_budget	12
4.6 * frame_budget	6
4.8 * frame_budget	1

All coefficients are coded if the deficit is ≤ 4.0 * frame_budget.

Mode Decision

FIG. 6 illustrates the processing of a frame at a TPE in accordance with the invention.

In the process 600, if the current picture to be processed is an I-picture (block 605), the terms frames_left[P] and frames_left[B] are initialized, and the term I_frame is set to one, indicating the current frame is an I_frame. Also, the term prev_IP_bypassed is set to true, and the term all_req is set to false. If all_req is true, every subsequent frame in the same GOP is processed in requantize or bypass mode.

prev_IP_bypassed set to true indicates that the bypass mode was used in the previous P (or I) frame of the GOP. It indicates that the "reconstruction buffer" (buffer 351) on the transcoder is empty. If prev_IP_bypass is FALSE, (i.e., the reconstruction buffer of the transcoder is not empty), avoid bypassing the current frame.

Frames_left(P) and *frames_left*(B) are the estimated number of P and B frames left until the next GOP. At the beginning of a GOP, frames_left(P) and frames_left(B) are initialized as:

frames_left(P) = average number of P frames per GOP over the last ten GOPs; and

frames_left(B) = average number of B frames per GOP over the last ten GOPs.

Any sufficiently large averaging window other than ten GOPs may be used. At startup, when previous data is not available for averaging, assume a nominal value based on the most commonly used configuration (e.g., GOP length = 15, two B frames for every pair of P frames, i.e. frames_left(P) = 4, frames_left(B)=10).

All_req (all requantize) is a binary flag that is reset at the beginning of a GOP, and it is set once a P or I frame has been requantized in the requantization mode.

If the current picture is not an I picture, at block 615, the terms frames_left[P] and frames_left[B] are initialized, and the term I_frame is set to zero, indicating the current frame is not an I_frame.

At block 616, if a panic mode is set, processing proceeds at block 618. At block 618, coefficient dropping is performed as required, and as discussed previously. Specifically, if the mode is "requantize" or "transcode", and "deficit" exceeds the thresholds (defined in the table), coefficient dropping is used.

At block 700, the processing mode selection is made using the process 700 of FIG. 7. Either a transcode, bypass or requantize mode is selected.

At block 620, if the current picture is a B-picture, it is processed using the designated mode at block 650. At block 655, the terms deficit and T(pic_type,mode) are updated.

At block 625, if the mode for the current picture is "bypass", and at block 630, if prev_IP_bypass is true, the frame is processed at block 650.

At block 630, if prev_IP_bypass is false, then all_req is set to true at block 645.

At block 635, prev_IP_bypass is set to false. At block 640, if the current frame is to be processed using the requantize mode, processing continues at

block 645. Otherwise, processing continues at block 650.

FIG. 7 illustrates the selection of a processing mode for a frame at a TPE in accordance with the invention.

At block 702, if the all_req or panic mode has been invoked, processing continues at block 745. Panic mode is invoked when the "deficit" exceed a threshold (e.g., 4.0*frame_budget, as defined in the table). In panic mode, the frame is either bypassed, or processed in requant mode with coefficient dropping.

If frame_target < original_frame_size, the requantize mode is selected (block 755). original_frame_size is the number of bits in the input frame. Otherwise, the bypass mode is selected (block 750). frame_target (or target output frame size) is the number of bits to be generated at the output of the transcoder for this frame. Since transcoding reduces the number of bits in a frame, transcoding or requantization should not be performed if the target is bigger than the input number of bits in the frame. frame_budget is the number of cycles budgeted to process the frame.

If all_req and panic are false (block 702), processing continues at block 705, where cycles_tr and cycles_avail are set as indicated. cycles_tr is the estimate of the number of cycles required to process the remaining frames of the GOP if every frame is are processed with mode=transcode. cycle_avail is the

number of cycles available (budgeted) for processing the remaining frames of this channel.

Let *frame_budget* be the number of processing cycles budgeted per frame for one video channel in a multiple channel TPE. frame_budget for channel i on a TPE is calculated as:

frame_budget[i] = ((throughput of the TPE in cycles per second) * comp[i] / (sum of complexity of all channels on the TPE)) * (1 / frame rate of the channel).

T(P,tr) is the estimated number of cycles needed to transcode a P frame. **T**(I,tr) and **T**(B, tr) are defined similarly for I and B frames, respectively. fashion. The variables **T**(P, req), **T**(I,req) and **T**(B,req) are the estimates for requantization. The values of T() are estimated from previously transcoded, or requantized, frames. At startup, these are initialized to some nominal value.

At block 710, if cycles_tr > cycles_avail, processing continues at block 745. Otherwise, processing continues at block 715, where if the current picture is a B frame, processing continues at block 720, where the processing cycles required is updated. Them at block 725, if cycles_req < frame_budget is false, processing continues at block 745 as discussed. If cycles_req < frame_budget is true (block 725), and prev_IP_bypassed is false (block 730), a transcode mode is set for the current picture (block 740).

The "transcode" mode is also set for the current picture (block 740) if prev_IP_bypassed is true (block 730), and frame_target < original_frame_size is true (block 735).

The "bypass" mode is set for the current picture (block 750) if prev_IP_bypassed is true (block 730), and frame_target < original_frame_size is false (block 735).

Accordingly, it can be seen that the present invention provides an efficient video processor system. wherein a processing mode is set for each input video frame/picture, e.g., as a full transcode mode, which uses motion compensation, a requantize mode which does not use motion compensation, or a bypass mode. The processing mode selection accounts for a number of processing cycles that are available to process a frame, and an expected processing requirement of the frame.

Furthermore, to avoid an overflow of an input buffer at each transcoder, a panic condition is invoked when a processing cycle deficit become too high, as measured by the frame storage capacity of the input buffer. In this case, the bypass or requantization mode is selected to speed the frames through the transcoder.

Although the invention has been described in connection with various preferred embodiments, it should be appreciated that various modifications and

adaptations may be made thereto without departing from the scope of the invention as set forth in the claims.

For example, one can use the mode selection algorithm to select a "mode" to encode a frame. The definition of "modes" could be the motion search range, for example, such that different "modes" have different processing cycle requirements.

What is claimed is:

1. A method for processing video data comprising video frames, comprising the steps of:

maintaining a budget of a number of processing cycles that are available at a processor to process the data;

maintaining an estimate of the number of processing cycles required by the processor to process the video data;

providing the video data to the processor;

wherein the processor operates in a plurality of modes; and

selecting one of the modes for processing each video frame according to a relationship between the number of budgeted processing cycles and the estimated number of required processing cycles.

2. The method of claim 1, wherein:

one of the modes is selected for each video frame.

3. The method of claim 1, wherein:

the estimated number of required processing cycles is updated after each video frame is processed.

4. The method of claim 1, wherein:

the number of budgeted processing cycles is updated after each video frame is processed.

5. The method of claim 1, wherein:

when a requantization mode is selected for one of an I and P video frame in a group of pictures (GOP) of the video data, the requantization mode is also selected for all subsequent P frames in the GOP.

6. The method of claim 1, wherein:

the number of budgeted processing cycles and the estimated number of required processing cycles are provided for remaining frames of a group of pictures (GOP) of the video data.

7. The method of claim 1, wherein:

the estimated number of required processing cycles associated with a current video frame is responsive to an actual number of processing cycles consumed for at least one previous video frame.

8. The method of claim 1, comprising the further step of:

storing the video frames in a buffer associated with the respective processor prior to processing the video frames; wherein:

the buffer comprises a smoothing buffer for accommodating variable processing times at the processor for the video frames in the different processing modes.

9. The method of claim 1, wherein:

the processor is in a multi-processor device.

10. The method of claim 1, wherein:

the different modes have different computational intensities.

11. The method of claim 1, wherein:

a plurality of channels of video data are processed at the processor, and the number of budgeted processing cycles and the estimated number of required processing cycles are maintained separately for each channel.

12. The method of claim 11, comprising the further step of:

for each respective channel, determining if there is a processing cycle deficit associated with a current video frame of the respective channel based on a carried-over processing cycle deficit, if any, from a previous frame of the respective channel, and a difference between: (a) an actual number of processing cycles used for the previous video frame of the respective channel, and (b) the number of budgeted processing cycles for the current video frame of the respective channel.

13. The method of claim 12, wherein:

a requantization mode is selected, with dropping of higher-frequency discrete cosine transform (DCT) coefficients of the current video frame of a respective channel, when it is determined that an overall processing cycle deficit exceeds a predetermined level.

14. The method of claim 1, wherein:

the modes include a full transcoding mode, a requantization mode, and a bypass mode.

15. The method of claim 14, wherein:

in the full transcoding mode, motion compensation processing of the video data in a pixel domain is performed.

16. The method of claim 14, wherein:

in the requantization mode, the video data is requantized in a frequency transform domain without performing motion compensation processing.

17. The method of claim 14, wherein:

in the bypass mode, the video data bypasses motion compensation processing and requantization.

18. The method of claim 14, comprising the further step of:

determining if there is processing cycle deficit associated with a current video frame based on a

carried-over processing cycle deficit, if any, from a previous frame, and a difference between: (a) an actual number of processing cycles used for the previous video frame, and (b) the number of budgeted processing cycles for the current video frame.

19. The method of claim 18, wherein:

one of the requantization mode and the bypass mode is selected for the current video frame when it is determined that there is a processing cycle deficit associated therewith.

20. The method of claim 18, wherein:

the processing cycle deficit is used in determining the estimated number of required processing cycles.

21. The method of claim 18, wherein:

the processing cycle deficit is associated with remaining frames of a group of pictures (GOP) of the video data.

22. The method of claim 18, wherein:

the selected mode for the current video frame is based on whether the processing cycle deficit associated therewith exceeds a predetermined level.

23. The method of claim 18, wherein:

one of the requantization mode and the bypass mode is selected for the current video frame when it is determined that the processing cycle deficit associated therewith exceeds a predetermined level.

24. The method of claim 18, wherein:

when the requantization mode is selected, and when it is determined that the processing cycle deficit associated therewith exceeds a predetermined level, higher-frequency discrete cosine transform (DCT) coefficients are dropped in the current video frame.

25. The method of claim 24, wherein:

the predetermined level is a function of an expected fullness level of a buffer associated with the processor in which the video frames are stored prior to processing.

26. The method of claim 24, wherein:

different levels of coefficient dropping are used according to a picture type of the current video frame.

27. An apparatus for processing video data comprising video frames, comprising:

means for maintaining a budget of a number of processing cycles that are available at a processor to process the data;

means for maintaining an estimate of the number of processing cycles required by the processor to process the video data;

means for providing the video data to the processor;

wherein the processor operates in a plurality of modes; and

means for selecting one of the modes for processing each video frame according to a relationship between the number of budgeted processing cycles and the estimated number of required processing cycles.

ABSTRACT

An efficient processing system, such as for transcoding video data. In an embodiment that is suitable for single or multiple processor embodiments, a processing mode is set for each input video frame, e.g., as a full transcode mode, which uses motion compensation, a requantization mode, which avoids motion compensation, or a bypass mode. The processing mode selection is based on a number of processing cycles that are available to process a frame, and an expected processing requirement of the frame. The bypass or requantization modes are selected to avoid a buffer overflow of the processor.

P A T E N T

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:)
)
Liu et al.)
)
Application No.:)
)
Filed: Herewith)
)

For: **PROCESSING MODE SELECTION FOR CHANNELS IN A VIDEO MULTI-PROCESSOR SYSTEM**

DRAWING REVIEW BRANCH
Commissioner for Patents
Washington, D.C. 20231

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as Express Mail (No. EL 632260034 US) addressed to BOX PATENT APPLICATION, Commissioner for Patents, Washington, D.C. 20231 on September 20, 2000.

By: Michele Hollis
Michele Hollis

TRANSMITTAL OF FORMAL DRAWINGS

Dear Sir:

Enclosed are seven (7) sheets of formal drawings for filing in the above-referenced patent application.

Please advise the undersigned attorney if correction is necessary.

Respectfully submitted,

Barry R. Lipsitz
Attorney for Applicant(s)
Registration No. 28,637
755 Main Street
Monroe, CT 06468
(203) 459-0200

Date: September 20, 2000
ATTORNEY DOCKET NO.: GIC-619

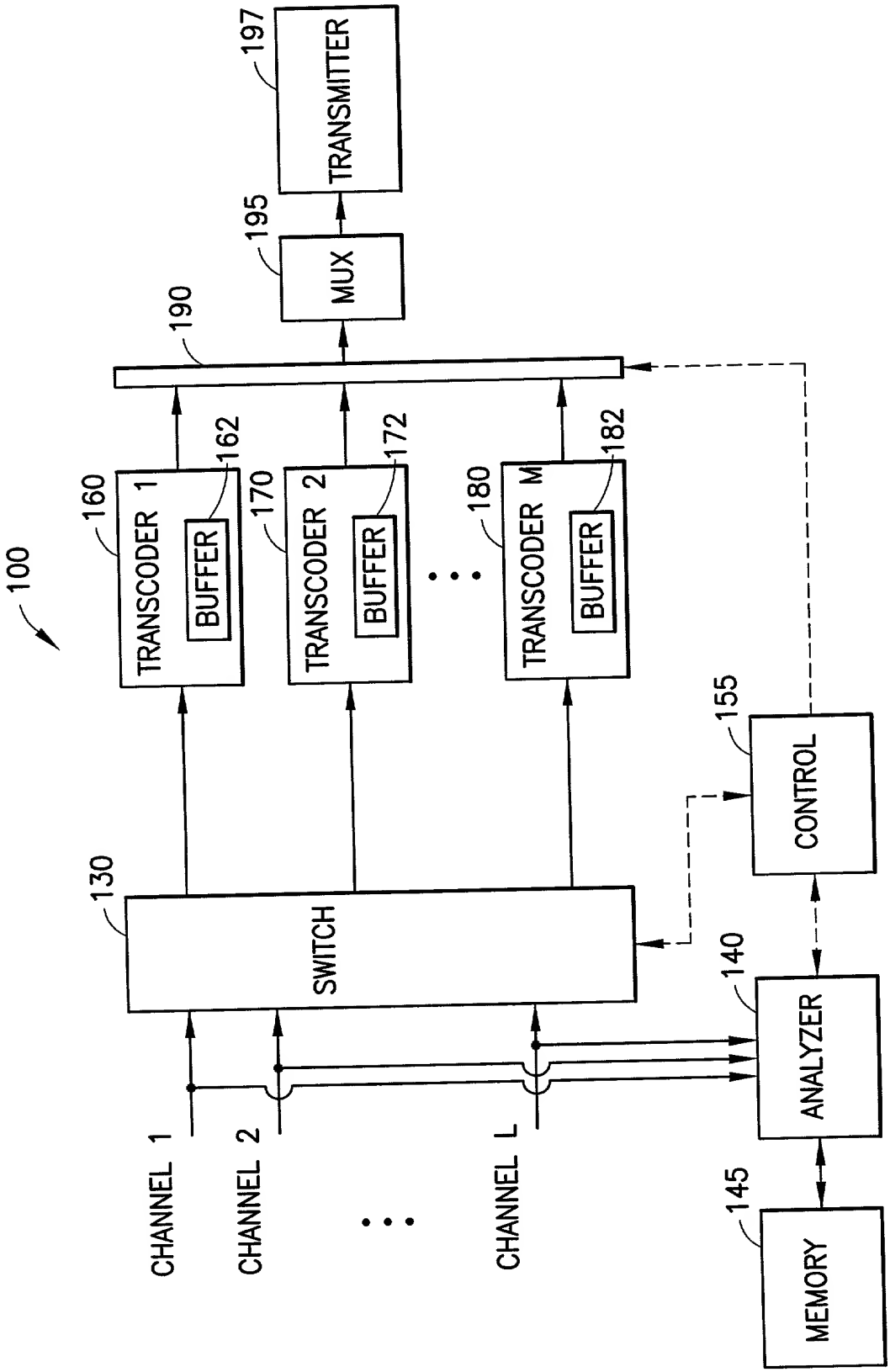
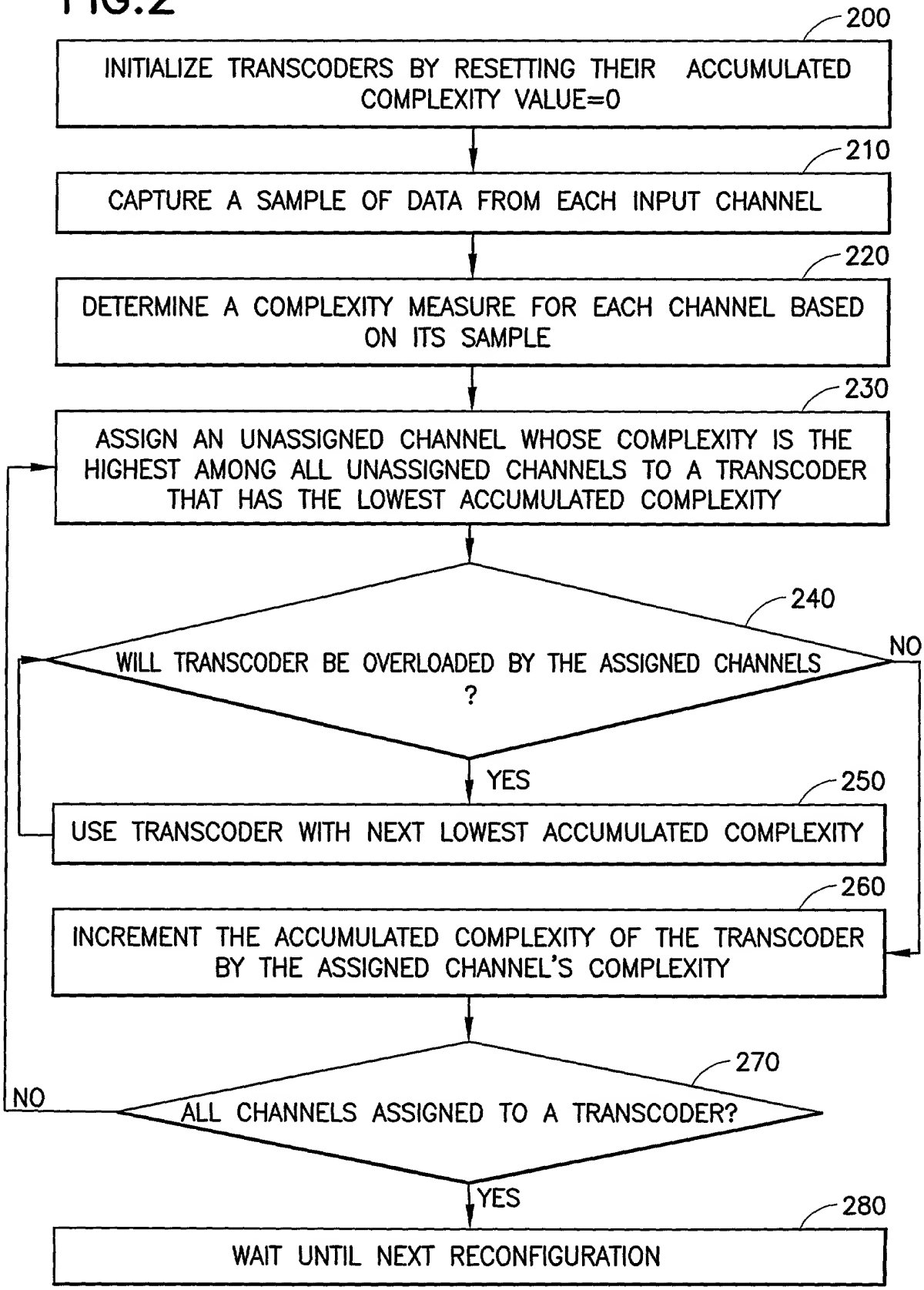

100
TRANSCODER 1
BUFFER
160
162
TRANSCODER 2
BUFFER
170
172
TRANSCODER M
BUFFER
180
182
190
MUX
195
TRANSMITTER
197
SWITCH
130
CONTROL
155
ANALYZER
140
MEMORY
145
CHANNEL 1
CHANNEL 2
CHANNEL L

FIG.1

FIG.2


200
INITIALIZE TRANSCODERS BY RESETTING THEIR ACCUMULATED COMPLEXITY VALUE=0
210
CAPTURE A SAMPLE OF DATA FROM EACH INPUT CHANNEL
220
DETERMINE A COMPLEXITY MEASURE FOR EACH CHANNEL BASED ON ITS SAMPLE
230
ASSIGN AN UNASSIGNED CHANNEL WHOSE COMPLEXITY IS THE HIGHEST AMONG ALL UNASSIGNED CHANNELS TO A TRANSCODER THAT HAS THE LOWEST ACCUMULATED COMPLEXITY
240
WILL TRANSCODER BE OVERLOADED BY THE ASSIGNED CHANNELS ?
NO
YES
250
USE TRANSCODER WITH NEXT LOWEST ACCUMULATED COMPLEXITY
260
INCREMENT THE ACCUMULATED COMPLEXITY OF THE TRANSCODER BY THE ASSIGNED CHANNEL'S COMPLEXITY
270
ALL CHANNELS ASSIGNED TO A TRANSCODER?
NO
YES
280
WAIT UNTIL NEXT RECONFIGURATION

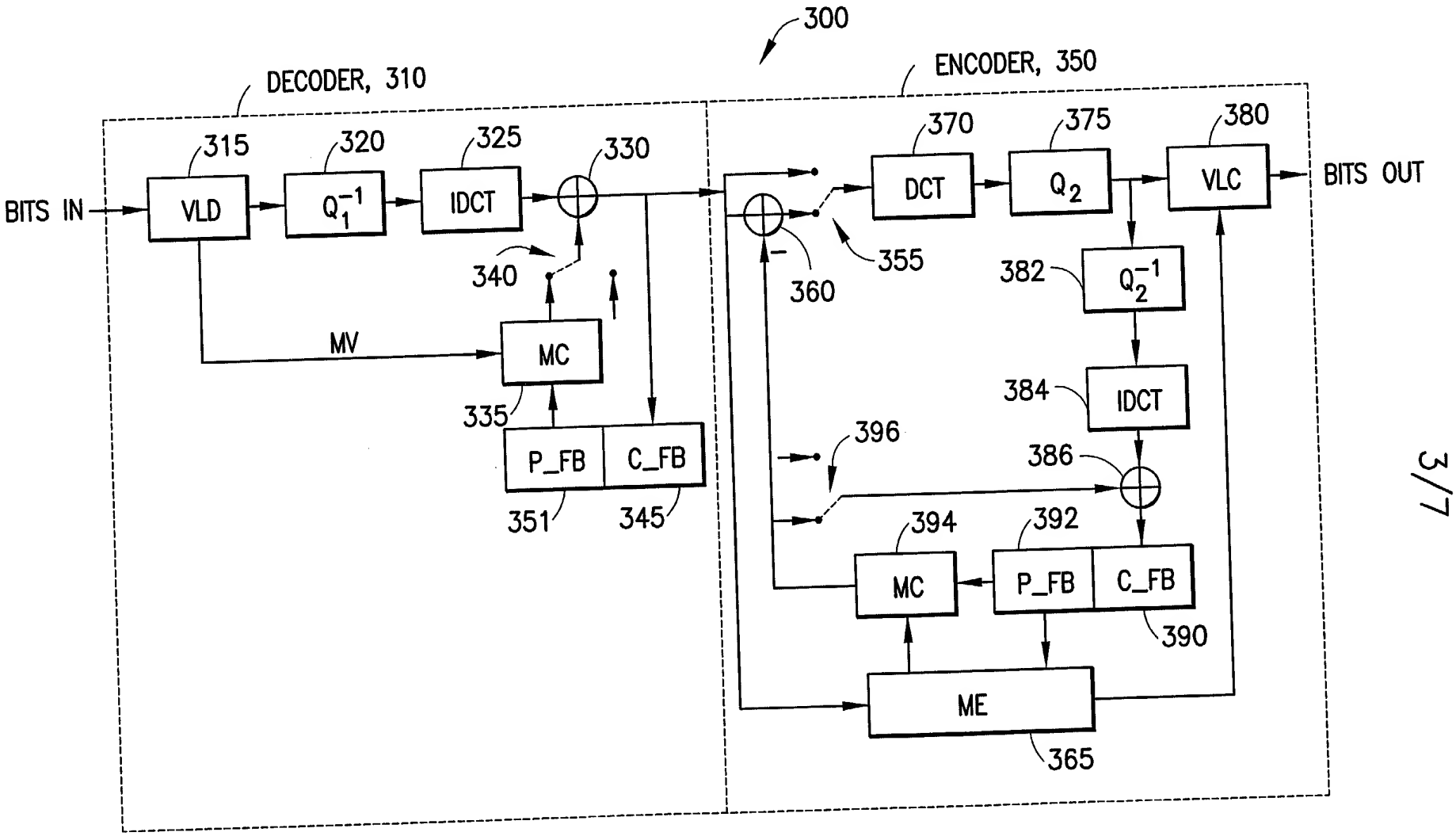


FIG.3(a)

PRIOR ART

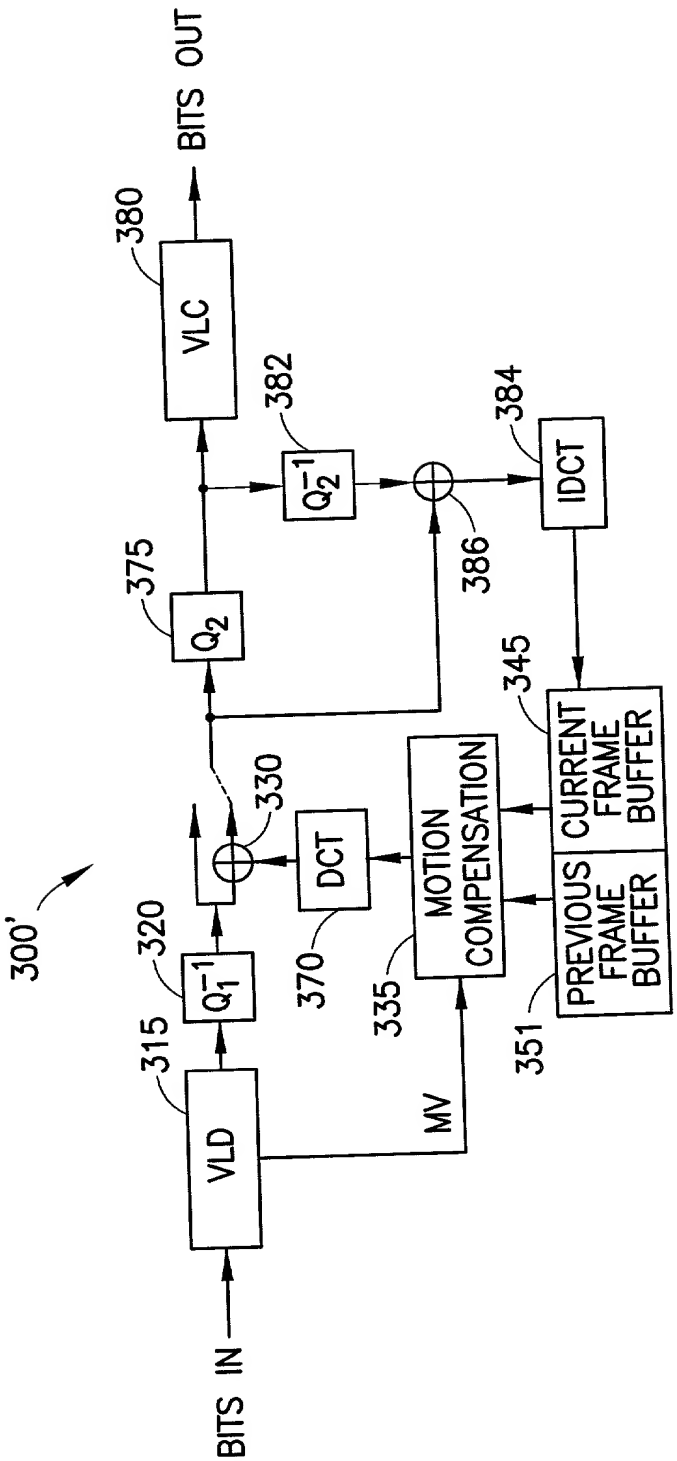

300'
BITS IN
VLD
315
Q_1^{-1}
320
DCT
370
330
MOTION COMPENSATION
335
MV
PREVIOUS FRAME BUFFER
351
CURRENT FRAME BUFFER
345
IDCT
384
386
Q_2^{-1}
382
Q_2
375
VLC
380
BITS OUT

FIG.3(b)

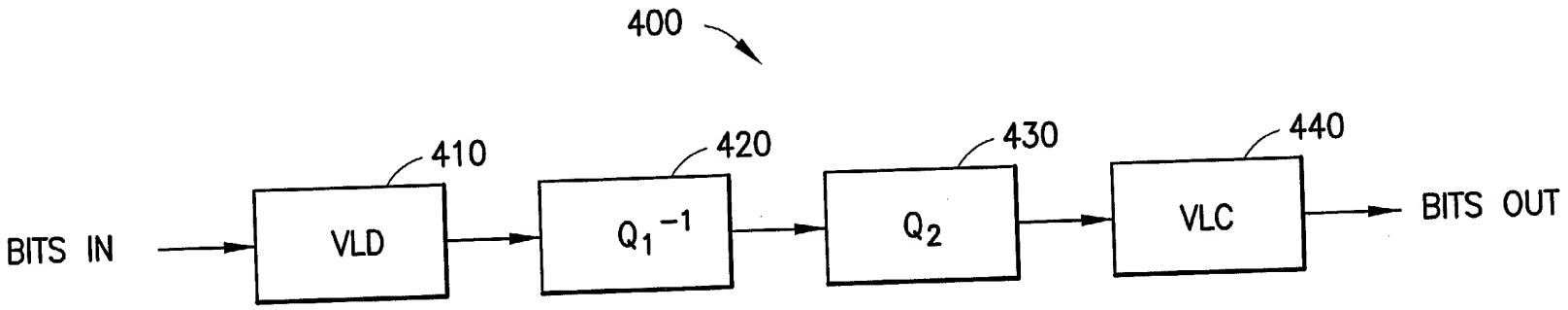

400
410
420
430
440
BITS IN
VLD
Q_1^{-1}
Q_2
VLC
BITS OUT

FIG.4

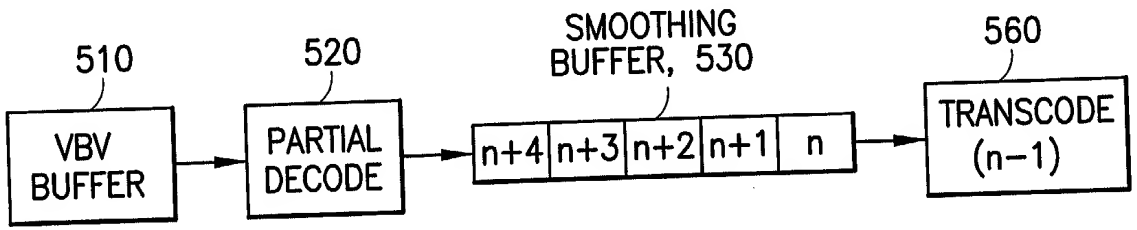

510
520
SMOOTHING BUFFER, 530
560
VBV BUFFER
PARTIAL DECODE
n+4
n+3
n+2
n+1
n
TRANSCODE (n−1)

FIG.5

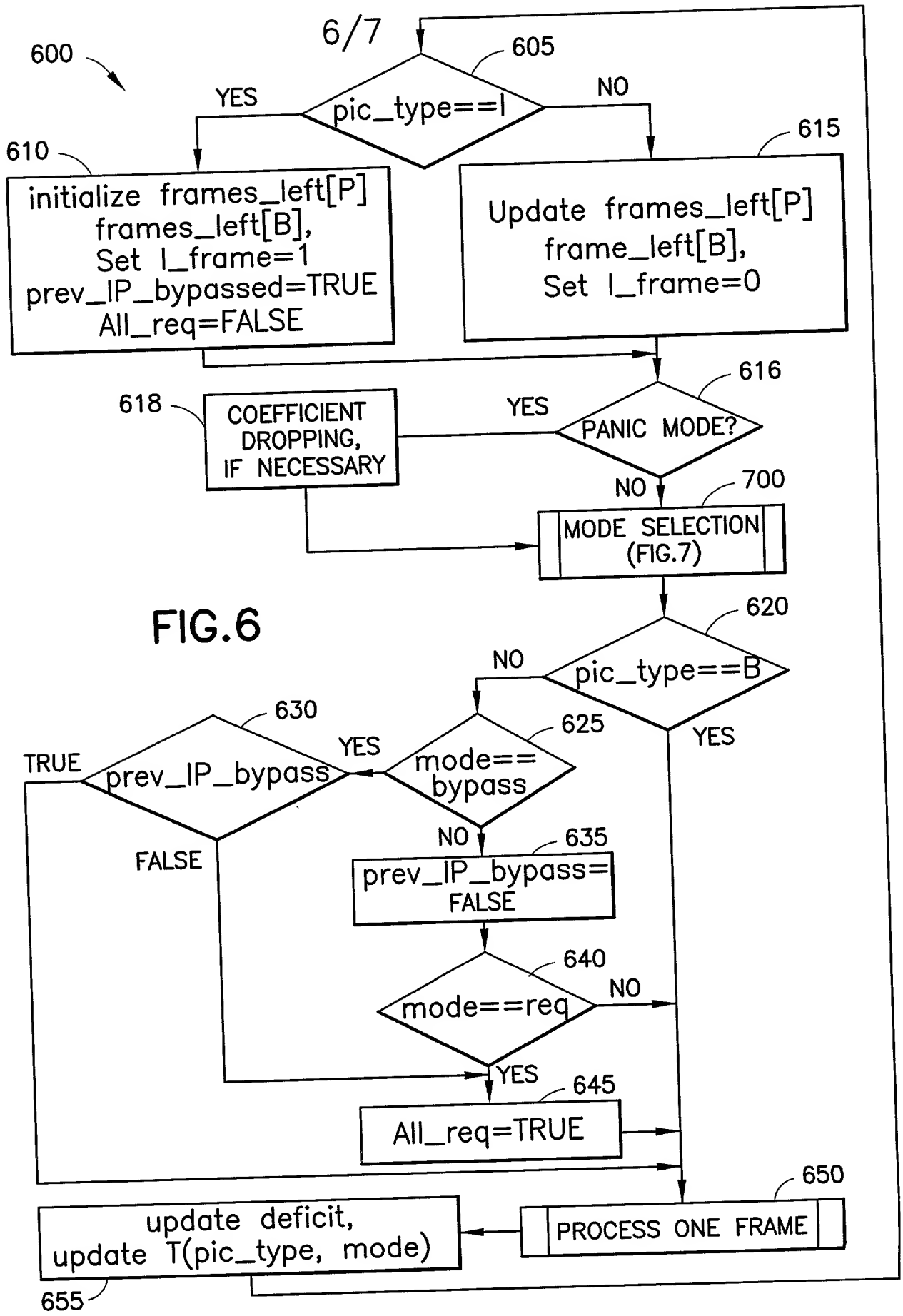

600
605
pic_type==I
YES
NO
610
initialize frames_left[P]
frames_left[B],
Set I_frame=1
prev_IP_bypassed=TRUE
All_req=FALSE
615
Update frames_left[P]
frame_left[B],
Set I_frame=0
616
618
COEFFICIENT
DROPPING,
IF NECESSARY
YES
PANIC MODE?
NO
700
MODE SELECTION
(FIG.7)
620
NO
pic_type==B
YES
630
625
TRUE
YES
prev_IP_bypass
mode==
bypass
NO
635
FALSE
prev_IP_bypass=
FALSE
640
mode==req
NO
YES
645
All_req=TRUE
650
update deficit,
update T(pic_type, mode)
PROCESS ONE FRAME
655

FIG.6

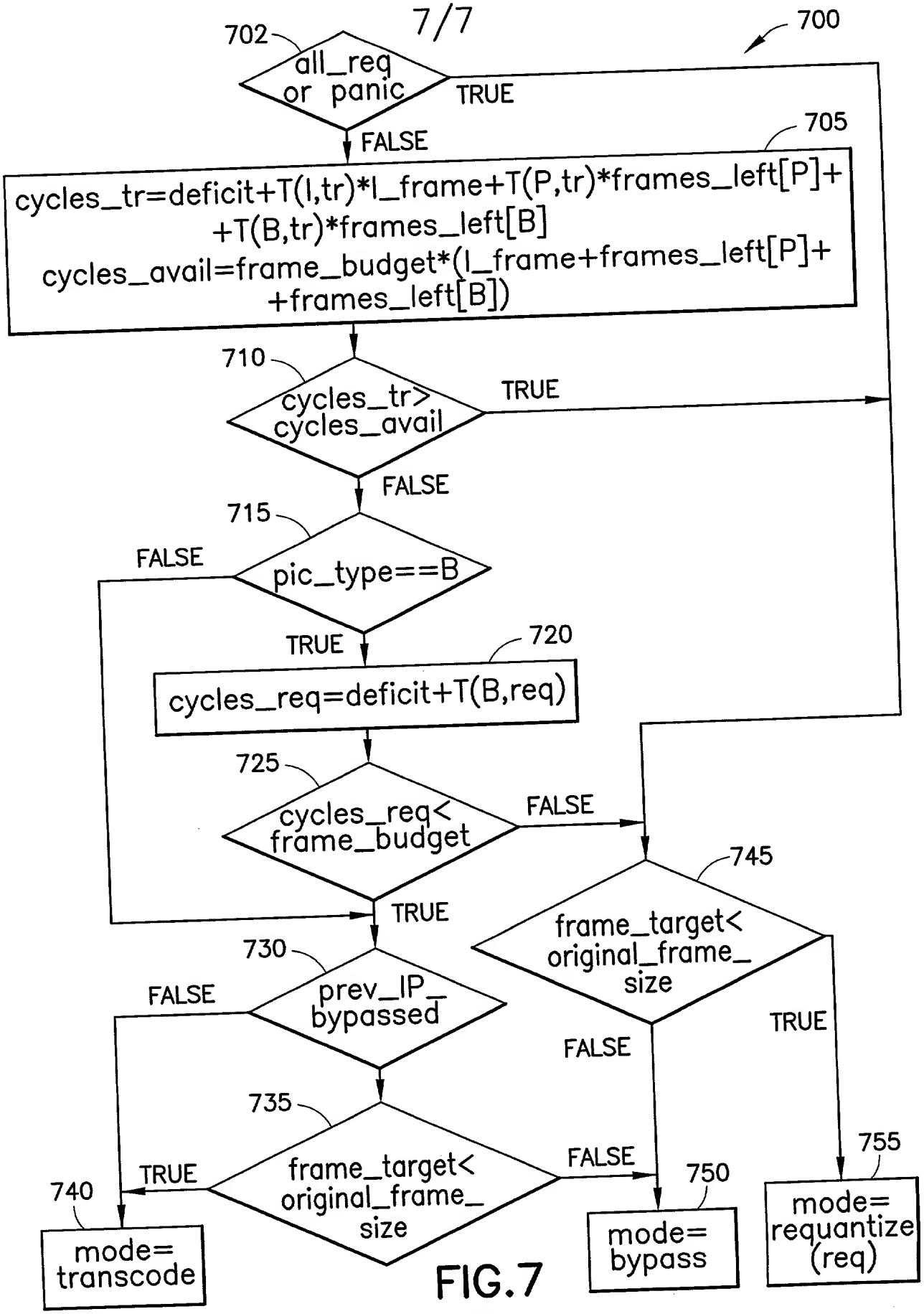

700
702
all_req or panic
TRUE
FALSE
705
cycles_tr=deficit+T(I,tr)*I_frame+T(P,tr)*frames_left[P]+
+T(B,tr)*frames_left[B]
cycles_avail=frame_budget*(I_frame+frames_left[P]+
+frames_left[B])
710
cycles_tr> cycles_avail
TRUE
FALSE
715
pic_type==B
FALSE
TRUE
720
cycles_req=deficit+T(B,req)
725
cycles_req< frame_budget
FALSE
TRUE
745
frame_target< original_frame_ size
TRUE
FALSE
730
prev_IP_ bypassed
FALSE
735
frame_target< original_frame_ size
TRUE
FALSE
740
mode= transcode
750
mode= bypass
755
mode= requantize (req)

FIG.7

DECLARATION, POWER OF ATTORNEY, AND PETITION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

PROCESSING MODE SELECTION FOR CHANNELS IN A VIDEO MULTI-PROCESSOR SYSTEM

the specification of which is attached hereto unless the following box is checked:

[ ] was filed on _____ as United States Application Number _____ or PCT International Application Number _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the U.S. Patent and Trademark Office all information known to be material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate or of any PCT international application having a filing date before that of the application on which priority is claimed:

			Priority Claimed
(Number)	(Country)	Month/Day/Year Filed	[ ] Yes [ ] No
(Number)	(Country)	Month/Day/Year Filed	[ ] Yes [ ] No

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date) - Month/Day/Year
(Application Number)	(Filing Date) - Month/Day/Year

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	**Parent Filing Date (MM/DD/YYYY)**	**Parent Patent Number (if applicable)**

And I hereby appoint: Barry R. Lipsitz, Registration No. 28,637, Ralph F. Hoppin, Registration No. 38,494 and Douglas M. McAllister, Registration No. 37,886, all of the firm of Barry R. Lipsitz, Attorney at Law, 755 Main Street, Bldg. 8, Monroe, Connecticut 06468, Telephone (203) 459-0200, my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Wherefore I pray that Letters Patent be granted to me for the invention or discovery described and claimed in the foregoing specification and claims, and I hereby subscribe my name to the foregoing specification and claims, declaration, power of attorney, and this petition.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor: Vincent LIU

Inventor's Signature Vincent Liu Date: 8-24-2000

San Diego **California** **TAIWAN**

Residence (City) (State or Foreign Country) Citizenship:

7714 Roan Road **San Diego, California 92129, U.S.A.**

Post Office Address (Post Office Address) (City) (State & Zip Code/Country)

Full name of second joint inventor: Robert S. NEMIROFF

Inventor's Signature Robt S Nemiroff Date: 8/24/00

Carlsbad **California** **U.S.A.**

Residence (City) (State or Foreign Country) Citizenship:

6718 Blue Point Drive **Carlsbad, California 92009, U.S.A.**

Post Office Address (Post Office Address) (City) (State & Zip Code/Country)

Full name of third joint inventor: Siu-Wai WU

Inventor's Signature Siu Wai Wu Date: 8-24-2000

San Diego **California** **HONG KONG**

Residence (City) (State or Foreign Country) Citizenship:

12655 Fairbrook Road **San Diego, California 92131, U.S.A.**

Post Office Address (Post Office Address) (City) (State & Zip Code/Country)

Full name of fourth joint inventor: **Ajay LUTHRA**

Inventor's Signature A. Luthra Date: 8/24/2000

San Diego **California** **U.S.A.**
Residence (City) (State or Foreign Country) Citizenship:

13695 Winstanley Way **San Diego, California 92130, U.S.A.**
Post Office Address (Post Office Address) (City) (State & Zip Code/Country)

Full name of fifth joint inventor: **Limin WANG**

Inventor's Signature L. Wang Date: 8/25/2000

San Diego **California** **CANADA**
Residence (City) (State or Foreign Country) Citizenship:

13641 Shoal Summit Drive **San Diego, California 92128, U.S.A.**
Post Office Address (Post Office Address) (City) (State & Zip Code/Country)